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(54) Micropump avoiding microcavitation.

(57) A micropump (1) which is reciprocatingly driven by a membrane (18) into subsequent outwards and inwards bulging movements, in response to the application of an excitation voltage to a piezoelectric microactuator 9. The application of the excitation voltage follows a wave form which includes rapidly ascending ramps which produce rapid decrease of the volume of the pump chamber, and slowly descending ramps which produce sufficiently moderate rates of increase of the volume of the pump chamber in order to avoid microcavitation.

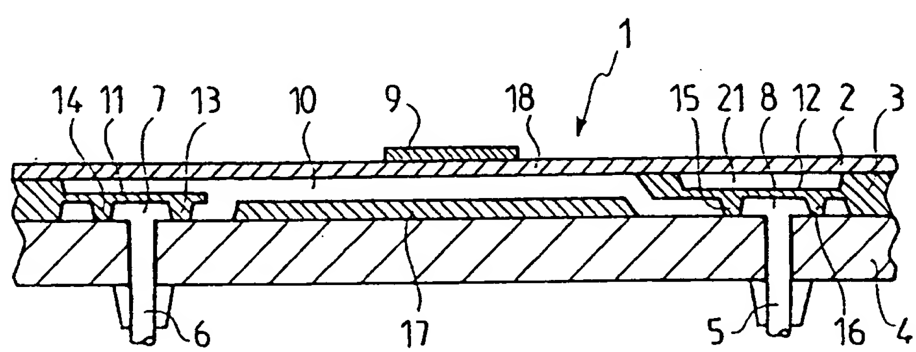

FIG. 1

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The present invention relates to a micropump comprising a structural intermediate member, which is at least partially sandwiched between an upper plate and a lower support plate, at least one of said upper plate and structural member forming a membrane, which structural member defines at least one valve element and a pump chamber, said membrane closing said pump chamber and carring a microactuator susceptible of causing said membrane to carry out a reciprocating outwards and inwards bulging in response to an excitation voltage applied to said microactuator from a control unit for said actuator, wherein the outwards and inwards bulging movements of said membrane increase and decrease respectively the volume of said pump chamber and are controlled by the variation of said excitation voltage which comprises an ascending ramp for one of the thrust phase or the suction phase of the micropump and a descending ramp for the other one of said two phases.

In an article published in "Sensors and Actuators, 15 (1988) 153-167" the article entitled "A piezoelectric micropump based on micromachining of silicon" of H.T.G. van Lintel, F.C.M. van de Pol and S. Bouwstra describes a micropump which is produced by micromachining of silicon and which comprises an inlet valve, an outlet valve, and a pump chamber which is closed by a glass membrane which carries a piezoelectric disc. This piezoelectric disc is capable of bending the membrane upwards and downwards in response to an applied excitation voltage, and creates thus a pumping effect within the pump chamber.

The electrical control of a piezoelectric actuator of micropumps is traditionally carried out in a way such as illustrated in Fig. 2 of British patent application 1 344 754, which describes a reciprocating pump. According to Fig. 2 of this British patent application, the ascending and the descending ramps of the pump control current are symmetric and this type of pump control has hitherto been used also for micropumps.

According to the specific geometrical configuration of a micropump as well as to material parameters, it has been advantageous to apply an ascending ramp of considerable steepness, in order to rapidly open the outlet valve during the decrease of the volume of the pump chamber in response to the application of an ascending voltage to the piezoelectric microactuator.

After a predetermined holding time, the excitation voltage has been reduced at the same rate as it had been increased during the ascending ramp, and it has been found by the inventor of the present application that problems have occured during the operation of a micropump using descending ramps for the excitation voltages which have essentially the same steepness as the ascending ramps, which problems are believed to be due to the occurrance of microcavitation following rapid expansion of the volume of the pump chamber at the beginning of the suction phase.

It is the object of the present invention to provide a micropump which avoids the above problem of microcavitation during the increase of the volume of the pump chamber, and this object is met according to the present invention by a micropump such as described hereabove which is further characterized in that the voltage variation of the descending ramp is selected such as to produce an outwards bulging of the membrane for the starting of the suction phase which is sufficiently moderate in order to avoid microcavitation.

According to an embodiment of the present invention the pump frequency is between approximately 1 and 10 Hz, the ascending ramp of the excitation voltage may last about one ms and the descending ramp may last at least 10 ms.

According to a particular embodiment of the present invention the descending ramp has a linear shape starting from the end of the holding phase during which the voltage is kept at maximum level, until the beginning of the next following ascending ramp.

In another embodiment of the present invention the descending ramp is linear and shorter than the time period between the end of the holding phase and the beginning of the next following ascending ramp.

In an alternative embodiment of the present invention the descending ramp follows an exponential or otherwise non-linearly decaying curve.

The maximum excitation voltage which is maintained during the holding phase is typically between 100 V and 150 V.

Further the present invention relates to a method of operating a micropump having a pump chamber which is closed by a pump membrane, which membrane is driven by a piezoelectric microactuator, whereby this method is characterized by the following steps:

- providing a micropump and a controllable voltage source;
- applying voltage from said voltage source to said piezoelectric microactuator whereby said applied voltage comprises alternating rapidly ascending ramps and slower descending ramps such as to;
- rapidly decrease the volume of said pump chamber in response to said rapidly ascending ramps; and
- sufficiently slowly increase the volume of said pump chamber in response to said slowly decreasing ramps in order to avoid microcavitation.

Typically in a micropump according to the present invention ascending ramps last about 1 ms and descending ramps last about 10 to 100 ms.

The present invention will now be described in more detail with reference to the drawings, whereby

Fig. 1 illustrates schematically a micropump in a non-operating condition,

Fig. 2 illustrates the same micropump in a condition corresponding to a point of time just after the beginning of a thrust phase,

Fig. 3 illustrates the same micropump at a condition approximately at the end of a suction phase,

Fig. 4a illustrates a wave form for the excitation voltage of the piezoelectric microactuator according to the prior art, and

Fig. 4b illustrates a wave form for the excitation voltage of a piezoelectric microactuator of a micropump according to the present invention.

With reference to Fig. 1, reference number 1 designates a micropump comprising a glass support body 4, a glass membrane 2 and sandwiched therebetween a silicon wafer 3, which has been machined by any appropriate technique such as photo lithography and etching in order to obtain a structure such as indicated in Fig. 1 in very simplified fashion.

The structure of the micropump of Fig. 1 is of course only an example, it being understood that the activation mode for a micropump according to the present invention is applicable to any other specifically structured micropump.

Details of the exact configuration or surface treatment of portions of the silicon wafer are not subject of the present invention and are therefore not referred to nor represented.

Further, micropump 1 comprises an inlet 6 and an outlet 5 for a liquid to be transported by the operation of the micropump, inlet 6 being provided with an inlet valve 7 and outlet 5 being provided with an outlet valve 8.

Inlet and outlet valves 7 and 8 comprise membranes 11 and 12, which carry on their lower surface ring-shaped projections 13, 14 and 15, 16, which are located such as to surround the opening holes of inlet and outlet 6, 5 at the interface level between glass plate 4 and silicon wafer 3.

Between inlet valve 7 and outlet valve 8, a pump chamber 10 is provided whereas the thickness of land 17 of the silicon wafer determines the volume of pump chamber 10.

Glass membrane 2 comprises a central portion 18 which carries a piezoelectric microactuator 9, which may be excited by an appropriate electric wave form in order to produce a periodically alternating contraction and expansion movement in a direction parallel to the plane of the membrane.

Since the microactuator is intimately attached to the membrane, the two elements together execute a bending movement according to the principle of a bimetallic strip, whereby the bending direction depends on the polarity of the applied voltage.

Figs. 2 and 3 illustrate the operation of the micropump according to Fig. 1, and like elements of the micropump according to Figs. 2 and 3 are therefore designated with the same reference numbers as in Fig. 1.

Upon application of the appropriate voltage, microactuator 9 executes a contraction movement and, together with glass plate 2, bends in a direction such as to assume an upwards directed concave shape, and due to the maintenance of the side portions of glass plate 2 on the silicon wafer, membrane 18 of the glass plate bulges downwards such as to decrease the volume of the pump chamber 10. In a first phase of this downwards movement of center portion 18 of the glass plate 2, membrane 12 of outlet valve 8 bulges upwards in response to the pressure build-up within pump chamber 10 and annular projections 15, 16 are lifted from their seat on the upper surface of glass plate 4 in order to permit escape of the liquid contained within pump chamber 10 through outlet 5.

At the same time, the pressure in pump chamber 10 causes inlet valve 7 to remain closed such as to avoid any escape of liquid from pump chamber 10 through inlet 6.

As will be seen from Fig. 2, microactuator 9 not only executes a bending movement but also a downwards movement due to the downwards bulging of center portion 18 of the glass membrane 2, whereas the degree of this downwards movement of microactuator 9 is a measure for the decrease of the volume within pump chamber 10.

Fig. 3 illustrates an operation phase of micropump 1 corresponding to the end of a suction stroke whereby microactuator 9 has been excited previously in order to assume, together with the glass plate 2, a configuration in which both elements together form an upwards convex shape such that center portion 18 bulges upwards, due to the fact that glass membrane 2 is withheld at the side edges on silicon wafer 3.

This upwards bulging of center portion 18 increases the volume of pump chamber 10 whereas pressure within pump chamber 10 is reduced such as to open inlet valve 7, whereby membrane 11 is slightly bent upwards under the pressure of liquid entering through inlet 6, whereas annular projections 13, 14 are lifted from their seat on the upper surface of glass plate 4 in order to permit liquid entering through inlet 6 to flow into pump chamber 10.

Simultaneously, outlet valve 8 is maintained in its closed position.

Pressure in chamber 21 which is located between the membrane of outlet valve 8 and glass membrane 2 is maintained at a level between minimum and maximum pressure of the liquid within pump chamber 10, in order to secure that outlet valve will securely open if pressure in pump chamber 10 essentially exceeds the pressure in chamber 21, and that the outlet valve is closed when the pressure in pump chamber 10 is essentially inferior to the pressure in chamber 21. Since a certain amount of pressure difference is required in order to overcome the pretension of the valve, this pressure difference has to be taken into account when regulating the pressure in chamber 21.

The pressure in chamber 21 may be atmospheric pressure for applications where the liquid which enters into the micropump is maintained under atmospheric pressure and where, accordingly, the suction pressure of the micropump is slightly below and the thrust pressure of the micropump is slightly above atmospheric pressure, however, the pressure in chamber 21 can be adapted to any desired value corresponding to the needs and the application of the micropump.

Microactuator 9 and membrane 18 together in Fig. 3 do not only perform a bending movement in the indicated sense, but also an upwards movement in response to the upwards bulging of said two elements, and the degree of this upwards movement is an indication of the increase of the volume of pump chamber 10.

During the upwards bulging of the microactuator 9 and the membrane 18, the volume of the pump chamber is increased and the pressure therein decreases accordingly in abrupt fashion if the excitation of the piezoelectric actuator is changed abruptly. Such rapid change of the pressure accompagnied by an increase of the volume results in a "boiling effect" of the liquid which is referred to as microcavitation. Gases which are dissolved in the liquid are suddenly set free in the form of microbubbles and hinder proper transportation of the liquid through the micropump.

Eventually, such microbubbles may form a large bubble through coalescence, which large bubble could bring the pump operation to a complete stop.

Fig. 4a illustrates a typical wave form for the excitation voltage of a prior art piezoelectric actuator for a micropump, whereby an ascending ramp 19 lasts approximately 1 ms, which is followed by a holding phase 22 at the end 24 of which begins the descending ramp 20 which lasts also approximately 1 ms. For the rest of the duration of a pump cycle which lasts between 100 and 1000 ms typically, the excitation voltage is kept at the lower level.

Fig. 4b shows the wave form of the excitation voltage according to the present invention, whereby the ascending ramp 19 is followed by holding phase 22 in conventional manner, however the descending ramp 25 follows a slowly and linearly descending line from the end 24 of the holding phase 22 until the starting point 23 of the next ascending phase.

The descending ramp according to Fig. 4b may last 10 to 100 ms depending on the entire duration of a pump cycle and on the duration of the holding phase 22.

It is understood of course, that the descending ramp 25 need not be linear, but could also follow an exponential or other shape such as indicated by dashed line 25' or according to a sinus function such as indicated by reference number 25".

Also, the duration of the descending phase need not be as long as the difference between the end point 24 of holding phase 22 and the starting point 23 for the net ascending ramp, but could be shorter. However it must be sufficiently long in order to produce a moderately fast expansion of the volume of the pump chamber such as to reliably avoid the formation of microcavitation.

Claims

1. A micropump comprising a structural intermediate member (3) which is at least partially sandwiched between an upper plate (2), and a lower support plate (4), at least one of said upper plate (2) and said structural member (3) forming a membrane (18), which structural member defines at least one valve element (7, 8) and a pump chamber (10), said membrane (18) closing said pump chamber and carrying a microactuator (9) susceptible of causing said membrane to carry out a reciprocating outwards and inwards bulging in response of an excitation voltage applied to said microactuator from a control unit for said actuator and wherein the outwards and inwards bulging movements of said membrane increase and decrease respectively the volume of said pump chamber 10 and are controlled by the variation of said excitation voltage which comprises an ascending ramp for one of the thrust phase or the suction phase of the micropump and a descending ramp for the other one of said two phases, characterized in that the voltage variation of the descending ramp is selected such as to produce an outwards bulging of the membrane for the starting of the suction phase which is sufficiently moderated in order to avoid microcavitation.

2. The pump of claim 1, wherein the ascending ramp of the excitation voltage lasts about 1 ms.

3. The pump of any one of claims 1 or 2, wherein the descending ramps last at least 10 ms.

4. The pump of any one of claims 1-3, wherein the descending ramp has a linear shape starting from the end of a holding phase 22 during which the voltage is kept at a maximum level, until the beginning of the next following ascending ramp 19.

5. The pump of any one of claims 1-3, wherein the descending ramp is linear and shorter than the time period between the end 24 of the holding phase 22 and the beginning 23 of the next following ascending ramp.

6. The pump of any one of claims 1-3, wherein the descending ramp 25' follows an exponential curve.

7. The pump of any one of claims 1-6, wherein the maximum excitation voltage is between 100 V and 150 V.

8. A method of operating a micropump having a pump chamber which is closed by a pump membrane, which membrane is driven by a piezoelectric microactuator, comprising the following steps:
   - providing a micropump and a controllable voltage source;
   - applying voltage from said voltage source to said piezoelectric microactuator, whereby said applied voltage comprises alternating rapidly ascending ramps and slower descending ramps, such as to;
   - rapidly decreasing the volume of said pump chamber in response to said rapidly ascending ramps; and
   - sufficiently slowly increasing the volume of said pump chamber in response to said slowly descending ramps in order to avoid microcavitation.

9. The method of claim 8 wherein the ascending ramps last about 1 ms and the descending ramps last about 10 to 100 ms.

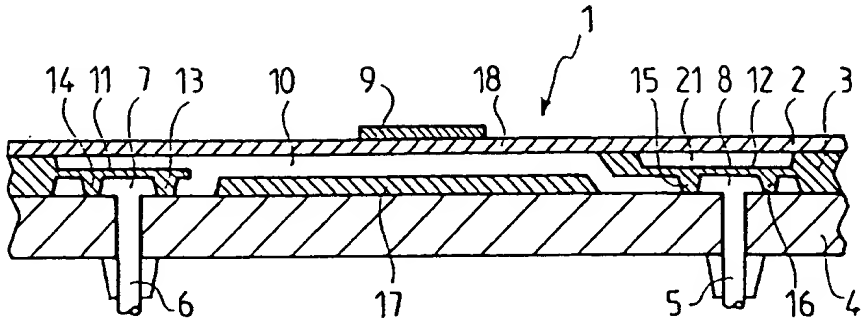

FIG. 1

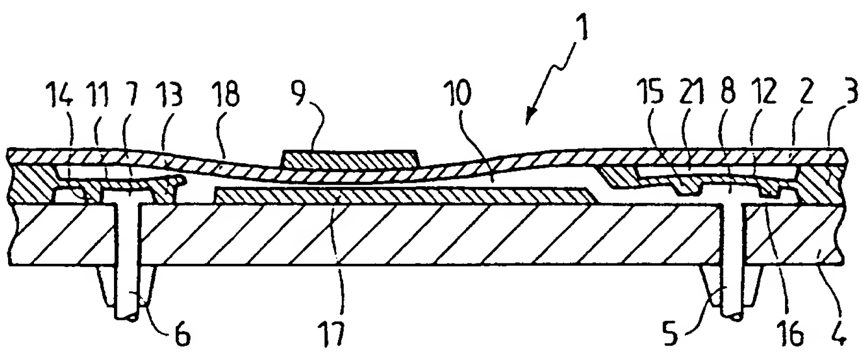

FIG. 2

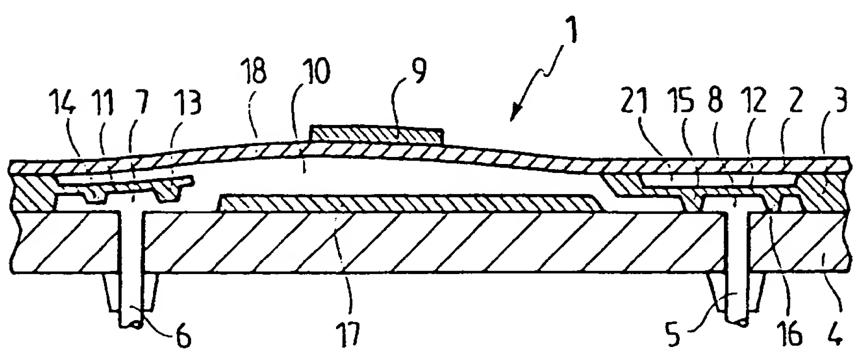

FIG. 3

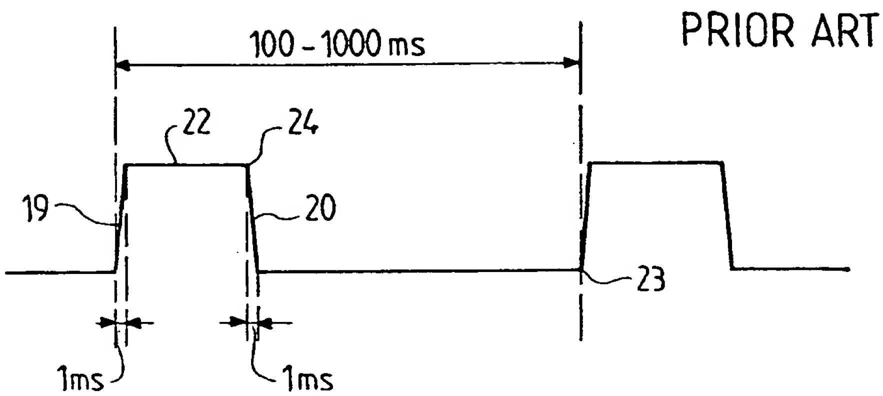
PRIOR ART
100 - 1000 ms
22
24
19
20
23
1ms
1ms

FIG. 4a

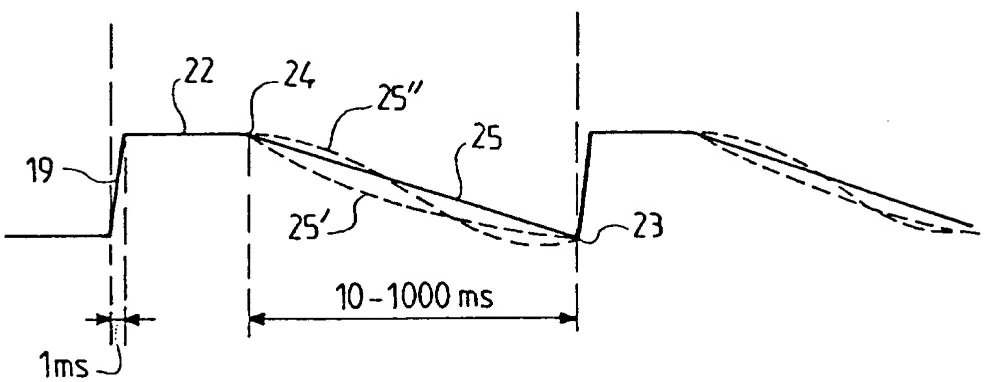
22
24
25″
25
19
25′
23
10 - 1000 ms
1ms

FIG. 4b

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(57) A micropump (1) which is reciprocatingly driven by a membrane (18) into subsequent outwards and inwards bulging movements, in response to the application of an excitation voltage to a piezoelectric microactuator 9. The application of the excitation voltage follows a wave form which includes rapidly ascending ramps which produce rapid decrease of the volume of the pump chamber, and slowly descending ramps which produce sufficiently moderate rates of increase of the volume of the pump chamber in order to avoid microcavitation.

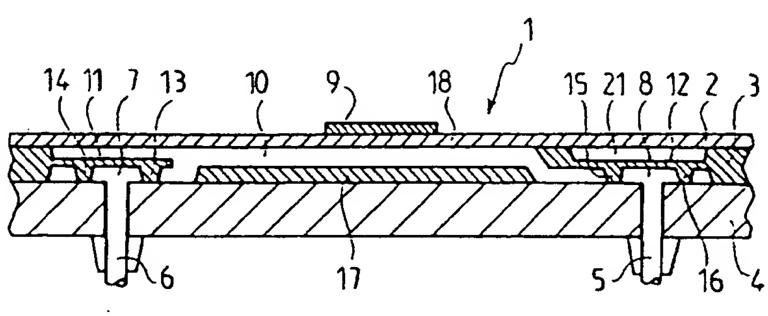

FIG. 1

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 93106828.2

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	EP - A - 0 393 602 (SEIKO EPSON CORP.) * Totality; especially figs. 2,7,9 *	1,4,6, 8	F 04 B 43/04
A		2,3,5, 7,9	
X	EP - A - 0 467 656 (TEKTRONIX INC.) * Totality; especially figs. 2,3,6,7 *	1,6,8	
A		2-5,7, 9	
X	US - A - 4 519 751 (BECKMAN et al.) * Totality; especially fig.6, pos. 72,78 *	1,6,8	
A	US - A - 4 344 743 (BESSMAN et al.) * Totality; especially fig. 3 *	1-9	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A	GB - A - 2 248 891 (WESTONBRIDGE INTERNATIONAL LIMITED) * Totality; especially page 9, lines 5-7 *	1-9	A 61 M 5/00 B 41 J 2/00 F 04 B 17/00 F 04 B 43/00 F 16 K 7/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	16-12-1993	WERDECKER

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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